Tropospheric Response in the Antarctic Circumpolar Wave along the Sea Ice Edge around Antarctica

WARREN B. WHITE

Scripps Institution of Oceanography, University of California, San Diego, La Jolla, California

PER GLOERSEN

Oceans and Ice Branch, Laboratory for Hydrosphere Sciences, NASA Goddard Space Flight Center, Greenbelt, Maryland

IAN SIMMONDS

School of Earth Sciences, University of Melbourne, Parkville, Victoria, Australia

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ABSTRACT

The Antarctic circumpolar wave (ACW) signal of a 3.7-yr period occurs along the sea ice edge forming around Antarctic each fall–winter–spring from 1982 to 2001. It was larger during the first decade than the second and has retracted sea ice extent (SIE) anomalies coinciding with warmer sea surface temperature, greater upward latent heat flux, and higher precipitation, driving deep convection in the troposphere associated with low-level convergence and upper-level divergence. Lower sea level pressure is displaced ~90° of phase to the west of retracted SIE anomalies, coinciding with increased extratropical cyclone density and intensity. The authors diagnose tropospheric thermal and potential vorticity budgets of this ACW signal using NCEP–NCAR reanalysis datasets, which show retracted SIE anomalies driving upper-level diabatic heating and low-level cooling, the former (latter) balanced mainly by vertical heat advection (poleward heat advection). This explains the anomalous poleward surface winds and deep convection observed over retracted SIE anomalies in this ACW signal. Thus, the vertical gradient of diabatic heating is balanced mainly by horizontal vortex tube advection at the low level and horizontal absolute vorticity advection at the upper level, together yielding the anomalous equivalently barotropic poleward wind response to the retracted SIE anomaly. Anomalous SIE-induced deep convection at the sea ice edge drives anomalous zonal (Walker-like) cells that teleconnect opposite phases in the ACW signal. It also drives anomalous Ferrell cells that teleconnect the ACW signal along the sea ice edge to that along the Subtropical Front near 35°S.

1. Introduction

White and Peterson (1996) and Jacobs and Mitchell (1996) found monthly sea surface height (SLH), sea surface temperature (SST), sea level pressure (SLP), and sea ice extent (SIE) anomalies in the Southern Ocean from 1982 to 1995 dominated by a broad interannual signal of a 3- to 7-yr period in zonal wavenumber–frequency spectra, propagating slowly eastward around the Southern Ocean in fixed phase with one another. They found that the four variables were dominated by global zonal wavenumber 2, with individual phases taking about 8 years to circle the globe at ~45° of longitude per year (i.e., ~0.08 m s^{-1}). They called this interannual signal the Antarctic circumpolar wave (ACW).

Corresponding author address: Dr. Warren B. White, Scripps Institution of Oceanography, University of California, San Diego, La Jolla, CA 92093-0230.
E-mail: wbwhite@ucsd.edu

Recently, we refined these results by conducting multitaper-method singular-value-decomposition (MTM-SVD) analysis on monthly SST, SLP, and sea ice concentration (SIC) anomalies extending in latitude from 30° to 90°S (centered on the fall–winter–spring sea ice edge) over the 20 years from 1982 to 2001. The corresponding spectrum of local fractional variance revealed five signals dominating climate variability near the sea ice edge; that is, one southern annular mode (SAM) signal near a 1.0-yr period and four ACW signals near 2.9-, 3.7-, 7.1-, and 17-yr periods, each characterized by eastward phase propagation. Together, these five signals explained ~50% of the variance in unfiltered winter SIC anomalies in the Ross and Weddell Seas, with the ACW at a 3.7-yr period dominating neighboring ACW signals by a factor of nearly 2 to 1 from 1983 to 1992.

Thus, the broadscale ACW signal of a 3–7-yr period observed by White and Peterson (1996) and Gloersen and White (2001) was composed of three narrowband

ACW signals at 2.9-, 3.7-, and 7.1-yr periods, with the ACW signal at a 3.7-yr period dominating the two neighboring signals from 1983 to 1992. It is characterized by global zonal wavenumber 2 with wave characteristics similar to those observed in the broadscale ACW observed by White and Peterson (1996) over this same epoch. In the present study, we have isolated the dominant ACW signal of the 3.7-yr period from its neighbors by appropriate bandpass filtering (Kaylor 1977). This allows us to investigate its character uncontaminated by interference from its neighbors. We focus on its behavior from 1983 to 1992, allowing us to continue to call it the ACW.

Modeling studies of the ACW (e.g., White et al. 1998; Baines and Cai 2000; White and Chen 2002) determined that its eastward phase propagation depends upon coupling between ocean and atmosphere, not on the eastward advection by the Antarctic Circumpolar Current (ACC). Thus, the ACW does not follow the ACC through the Southern Ocean. Rather, Peterson and White (1998), White and Chen (2002), and White et al. (2002) found the ACW composed of two main tracks; that is, a northern track following the Subtropical Front across the eastern Atlantic, Indian, and western and central Pacific sectors between 30° and 45°S and a southern track along the fall–winter–spring sea ice edge forming around Antarctica each year near 63°S. Both tracks converge at Drake Passage as the ACW propagates from the eastern Pacific sector to the western Atlantic sector.

The main issue in understanding ocean–atmosphere coupling in the ACW is the troposphere response to SST and SIE anomalies. White and Chen (2002) explained this response to SST anomalies in the ACW along the Subtropical Front by diagnosing the troposphere thermal, vorticity, and potential vorticity budgets along this track. They found warm SST anomalies driving upward latent heat flux and greater precipitation, generating upper-level diabatic heating and low-level diabatic cooling in the troposphere. The former is balanced mainly by upward thermal advection and the latter is balanced mainly by poleward thermal advection. This yields anomalous ascending motion throughout the troposphere (i.e., deep convection), accompanied by corresponding low-level convergence and upper-level divergence, and poleward low-level wind anomalies. In the vorticity budget, the anomalous low-level convergence is balanced mainly by the anomalous poleward advection of planetary vorticity, also yielding poleward low-level wind anomalies. In the potential vorticity budget, the anomalous vertical gradient of diabatic heating is balanced at the low level by a combination of anomalous poleward advection of mean vortex tubes and planetary vorticity, both of similar magnitude. This explains why poleward meridional surface wind (MSW) anomalies come to be collocated with warm SST anomalies in the ACW along this track. In the present study, we conduct a similar diagnostic study on the southern track of the ACW along the fall–winter–spring sea ice edge around Antarctica.

The ACW along the fall–winter–spring sea ice edge has anomalous retracted SIE, warm SST, poleward MSW, and reduced SIC propagating eastward together around more than three-quarters of the Southern Ocean from 30° eastward to 110°E (Gloersen and White 2001). The memory of the ACW in the sea ice pack from one austral winter to the next is conveyed by the upper-ocean diabatic heat storage associated with SST anomalies in the ACW. Yet, this raised the question as to whether SIE and SIC anomalies along the sea ice edge act as passive tracers for the ACW or whether they participate in a coupled interaction between the ocean and atmosphere. Deser et al. (2000) found SIE anomalies actively participating in the coupling by producing sensible-plus-latent heat flux anomalies with magnitudes on the order of the climatological estimates themselves, much larger than those associated with SST anomalies over the open ocean. They found this to have a significant impact on the troposphere circulation near the sea ice edge in the North Atlantic Ocean. In the present study, we find SIE anomalies in the ACW signal along the fall–winter–spring sea ice pack around Antarctica producing upward latent heat flux anomalies, but with magnitudes similar to those driven by SST anomalies along the northern track of the ACW (White and Chen 2002). However, we find it having much greater impact on tropospheric circulation at the sea ice edge, generating deep convection and meridional surface wind responses 2–3 times those along the Subtropical Front.

To understand this, we seek the dominant thermodynamic balances that govern the ACW along the fall–winter–spring sea ice edge by diagnosing its tropospheric thermal and potential vorticity budgets. We utilize the National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP–NCAR) global atmosphere reanalysis (Kistler et al. 2001), following the methodology of White and Chen (2002). We conduct this diagnostic study for the 10 years from 1983 to 1992 when the 3.7-yr period ACW signal was robust. We find anomalous SIE-induced latent heat flux driving mid- to upper-level diabatic heating and low-level cooling, the former balanced mainly by upward thermal advection and the latter balanced by poleward thermal advection as in White and Chen (2002) but in different proportion. Even so, this balance explains the collocation of anomalous poleward MSW and deep convection with retracted SIE anomalies. It also reveals a new finding; that is, the anomalous SIE-driven deep convection along the fall–winter–spring sea ice edge instigates anomalous Ferrell cells and zonal (Walker-like) cells. The anomalous zonal cells teleconnect opposite phases of the ACW signal along the sea ice edge, while the Ferrell cells teleconnect the various phases of the ACW along the sea ice edge equatorward across the Southern Ocean to opposite phases in the ACW along the Subtropical Front.